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(54) **METHOD FOR PREVENTING WHEEL SPIN ON STOPPED VEHICLES**

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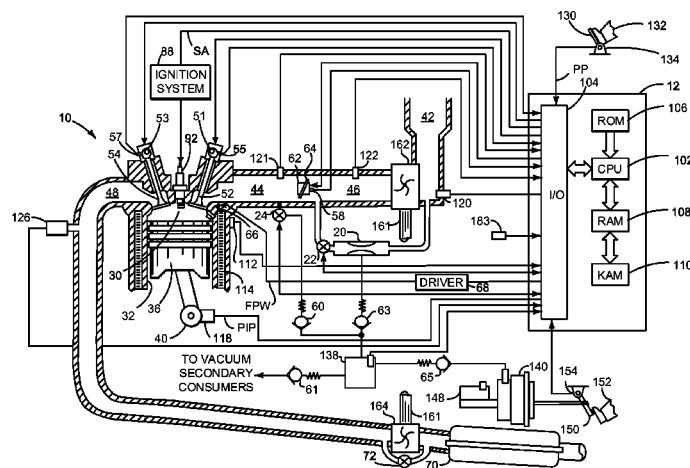
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(57) **ABSTRACT**

A method comprising: applying a brake force to all four wheels of a motor vehicle to stop the vehicle while torque continues to be applied to its driven wheels; and preventing wheel slippage of the driven wheels by reducing the applied torque when the vehicle is stopped or nearly stopped from moving in a forward direction. In this way, unintentional lateral movement of the vehicle due to creep torque applied to the driven wheels on slippery surfaces can be prevented or corrected.
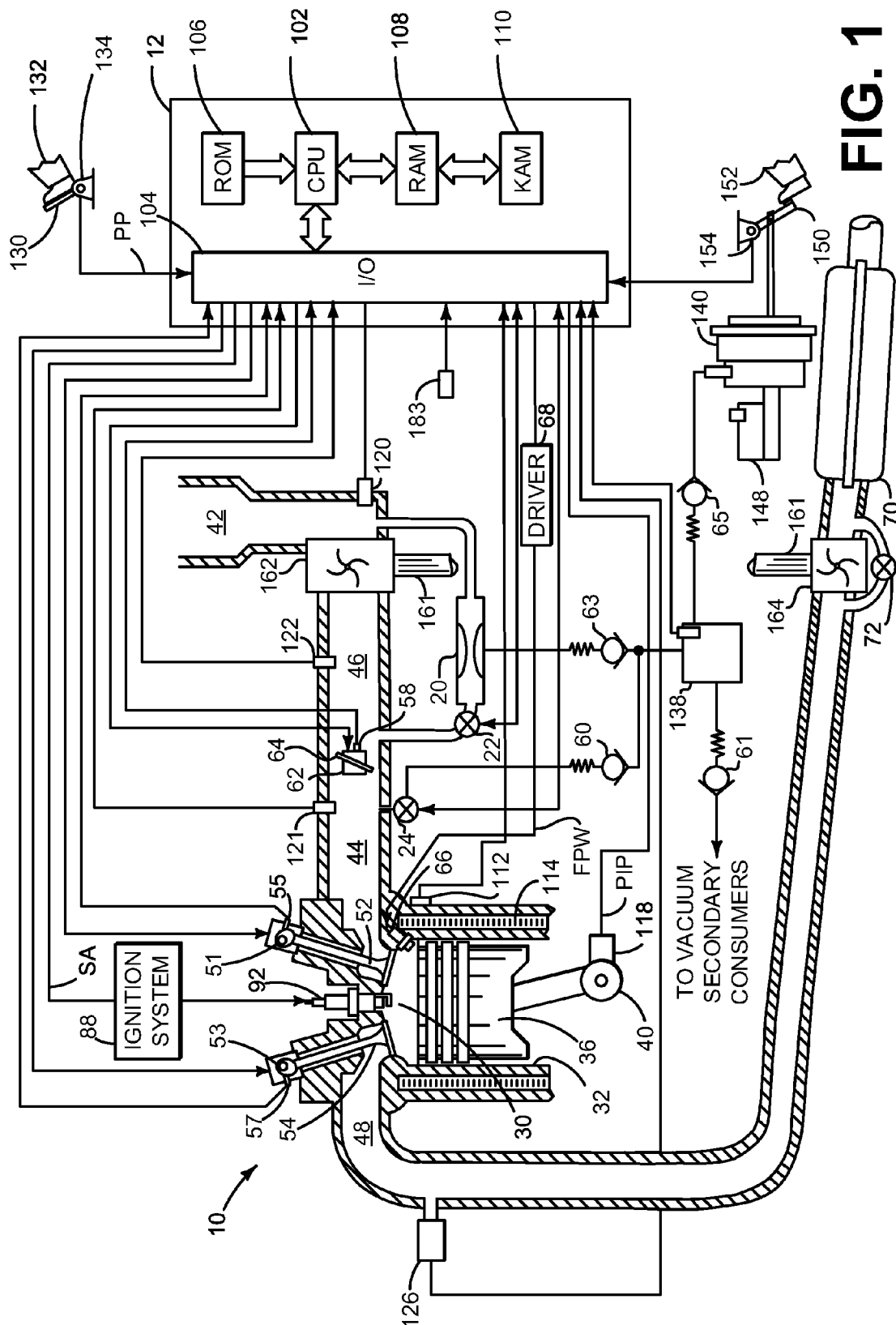
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FIG. 1

FIG. 2

START

305

Evaluate Operating
Conditions

300

310

Accelerator Pedal
Depressed?

YES

NO

315

Non-Driven Wheel
Speed < $v_{threshold}$?

NO

YES

320

Brake Boost Vacuum
< $V_{threshold}$?

NO

YES

335

Maintain Operating
Conditions

325

Engine
Speed > $Sp_{threshold}$?

NO

YES

330

Reduce Torque To Driven Wheels

Upshift Transmission   326

Slip Transmission Clutch   327

Retard Ignition Timing   328

END

FIG. 3

START

405
Evaluate Operating
Conditions

400

410
Accelerator
Pedal Depressed?

YES

NO

415
Non-Driven
Wheel Speed = 0?

NO

YES

420
Driven Wheel Slip
> Slip Threshold?

NO

425
Maintain Operating
Conditions

END

YES

430
Reduce Torque To Driven Wheels

Upshift Transmission	431
Slip Transmission Clutch	432
Shift Transmission To Neutral	433
Retard Ignition Timing	434

Apply Additional Brake Force To Driven Wheels

| Increase Brake Pressure To Driven Wheels | 435 |
| Apply Electric Parking Brake To Driven Wheels | 436 |

FIG. 4

START

505
Evaluate Operating
Conditions

510
Accelerator Pedal
Depressed?

YES

NO

515
Non-Driven Wheel
Speed < $v_{threshold}$?

NO

YES

520
Engine
Speed > $Sp_{Threshold}$?

NO

YES

530
Maintain Operating
Conditions

525
Apply Substantially Constant Torque To
Driven Wheels By Applying Transmission
Gear Related To Engine Idle Speed

END

500

FIG. 5

600

610

Brake Pedal
Position

615

Vehicle Speed

625   620

0

Engine Idle
Speed

630

635

Transmission
Gear

3rd

2nd

1st

640

Creep Torque

650

Brake Boost
Vacuum

665

660

t₀   t₁   t₂   Time

FIG. 6

FIG. 7

METHOD FOR PREVENTING WHEEL SPIN ON STOPPED VEHICLES

FIELD OF THE INVENTION

The present application relates generally to the control of a vehicle, and particularly to a system and method for controlling wheel spin on a stopped vehicle.

BACKGROUND AND SUMMARY

An internal combustion engine in a rear-wheel-drive vehicle with an automatic transmission supplies a torque to the rear wheels at all times when the transmission is in gear. The torque produced when a vehicle is stopped or moving at a very low speed is commonly known as creep torque. This creep torque purposefully causes the vehicle to accelerate when the driver's foot is not on the vehicle's brake pedal. If the driver does not want the vehicle to move, the driver may counter the creep torque with a braking force by pressing the brake pedal.

The inventors herein have recognized that, during cold weather at an initial engine start, the engine idle speed is high, say 1200 rotations per minute. High engine idle speed causes the transmission's torque converter to create a larger than usual creep torque, thereby driving the rear wheels. Furthermore, during these conditions the engine vacuum is low, because the engine is throttled less at the high engine speed and vacuum is consumed by the front end accessory drive, torque converter, catalyst heating, and cold engine friction needs. Thus brake booster vacuum can be low, a consequence further exacerbated by low atmospheric pressure at high altitude.

This combination of conditions may result in slippage of the driven wheels, such as the rear wheels of a rear wheel drive vehicle, if one or more of the rear wheels are on a low friction surface such as ice or snow. Suppose that the vehicle's driver applies enough braking force to stop the front wheels and the vehicle. From the driver's point of view, the driver is doing all that is required. If the rear wheels begin to spin, the tires lose their traction and the rear portion of the vehicle can slide sideways. The driver may either not know to arrest this with greater braking force or may be unable to arrest this with sufficient brake line pressure.

The inventors herein have recognized the above issue and have devised various approaches to address it. In particular, systems and methods for preventing or stopping wheel slippage on a stopped or nearly stopped vehicle are disclosed. In one example, a method, comprises: applying a brake force to all four wheels of a motor vehicle to stop the vehicle while torque continues to be applied to its driven wheels; and preventing wheel slippage of the driven wheels by reducing the applied torque when the vehicle is stopped or nearly stopped from moving in a forward direction. In this way, unintentional lateral movement of the rear portion of a vehicle due to creep torque can be prevented.

In another example, a method, comprises: applying a brake force to all four wheels of a motor vehicle to stop the vehicle while torque continues to be applied to its driven wheels; and in response to wheel slippage of the driven wheels when the vehicle is stopped from moving in a forward direction, reducing the applied torque to reduce the slippage. In this way, unintentional lateral movement of the rear portion of a vehicle due to creep torque can be stopped.

In another example, a system for controlling the driven wheels of a motor vehicle, comprises: a braking system coupled to the driven wheels and non-driven wheels of the vehicle, the braking system responsive to an operator controlled brake; an internal combustion engine coupled to the driven wheels through an automatic transmission; an air intake system including a throttle coupled to an intake of the engine, the throttle responsive to an operator controlled accelerator pedal; the automatic transmission having electrically actuated hydraulic clutches to engage one of a plurality of gears having different gear ratios, each of the gears when engaged coupling engine torque modified by the engaged gear to the driven wheels; and a controller controlling the engine and the transmission, the controller actuating a different one of the selected gears for each one of a range of predetermined speeds of the engine to provide a substantially constant torque applied to the driven wheels over the range of engine speeds when the throttle has been moved to an idle position and the braking system has slowed the vehicle below a predetermined speed or has stopped the vehicle. In this way, unintentional lateral movement of the rear portion of a vehicle due to creep torque may be prevented and stopped and a consistent creep torque may be applied at all times.

The above advantages and other advantages, and features of the present description will be readily apparent from the following Detailed Description when taken alone or in connection with the accompanying drawings.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a block diagram of a vehicle powertrain.

FIG. 2 is an example powertrain system layout.

FIG. 3 depicts a flow chart for an example high-level method for preventing wheel slippage on a stopped vehicle.

FIG. 4 depicts a flow chart for an example high-level method for stopping wheel slippage on a stopped vehicle.

FIG. 5 depicts a flow chart for an example high-level method for stopping wheel slippage on a stopped vehicle.

FIG. 6 shows an example timeline for preventing wheel slippage on a stopped vehicle.

FIG. 7 shows an example timeline for stopping wheel slippage on a stopped vehicle.

DETAILED DESCRIPTION

The present description is related to preventing wheel slippage for a stopped vehicle. In one example, the engine may be as illustrated in FIG. 1. Further, the engine may be part of a vehicle powertrain as illustrated in FIG. 2. Preventing wheel slippage for a stopped vehicle may be controlled as shown in the sequence of FIG. 3. Stopping wheel slippage for a stopped vehicle may be controlled as shown in the sequence of FIG. 4. Substantially constant torque may be applied to driven wheels as shown in the sequence of FIG. 5. Example timelines for preventing and stopping wheel slippage of a stopped vehicle are shown in FIGS. 6 and 7.

Referring to FIG. 1, internal combustion engine 10, comprising a plurality of cylinders, one cylinder of which is shown in FIG. 1, is controlled by electronic engine control-

ler 12. Engine 10 includes combustion chamber 30 and cylinder walls 32 with piston 36 positioned therein and connected to crankshaft 40. Combustion chamber 30 is shown communicating with intake manifold 44 and exhaust manifold 48 via respective intake valve 52 and exhaust valve 54. Each intake and exhaust valve may be operated by an intake cam 51 and an exhaust cam 53. The position of intake cam 51 may be determined by intake cam sensor 55. The position of exhaust cam 53 may be determined by exhaust cam sensor 57.

Fuel injector 66 is shown positioned to inject fuel directly into cylinder 30, which is known to those skilled in the art as direct injection. Alternatively, fuel may be injected to an intake port, which is known to those skilled in the art as port injection. Fuel injector 66 delivers liquid fuel in proportion to the pulse width of signal FPW from controller 12. Fuel is delivered to fuel injector 66 by a fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown). Fuel injector 66 is supplied operating current from driver 68 which responds to controller 12. In addition, intake manifold 44 is shown communicating with optional electronic throttle 62 which adjusts a position of throttle plate 64 to control air flow from intake boost chamber 46.

Compressor 162 draws air from air intake 42 to supply boost chamber 46. Exhaust gases spin turbine 164 which is coupled to compressor 162 via shaft 161. Vacuum operated waste gate actuator 72 allows exhaust gases to bypass turbine 164 so that boost pressure can be controlled under varying operating conditions. Vacuum is supplied to waste gate actuator 72 via vacuum reservoir 138. Vacuum reservoir 138 may be supplied vacuum from intake manifold 44 via intake manifold vacuum flow control valve 24 and check valve 60. Optional intake manifold vacuum flow control valve 24 is operated via an electrical signal from controller 12. In some examples, check valve 60 may be omitted.

Vacuum reservoir 138 may also be supplied vacuum via ejector 20. Ejector vacuum flow control valve 22 may be opened to permit compressed air from compressor 162 to pass through ejector 20. Compressed air passes through ejector 20 and creates a low pressure region within ejector 20, thereby providing a vacuum source for vacuum reservoir 138. Air flowing through ejector 20 is returned to the intake system at a location upstream of compressor 162. In an alternative example, air flowing through the ejector 20 may be returned to the air intake system via conduits to the intake manifold at a location downstream of throttle 62 and at a location upstream of compressor 162. In the alternative configuration, valves may be placed between the outlet of ejector 20 and intake manifold 44 as well as between the outlet of ejector 20 and air intake 42. Check valve 63 ensures air does not pass from ejector 20 to vacuum reservoir 138. Air exits ejector 20 and reenters the engine air intake system at a location upstream of compressor 162.

While ejector 20 is useful for increasing intake manifold vacuum and increasing vacuum level, it may not have capacity to provide as much vacuum as is desired in a short amount of time. Further, the performance of ejector 20 may be reduced during times when accelerator pedal 130 is not depressed or when engine torque demand is low since vacuum provided by ejector 20 increases as air flow through ejector 20 increases. Consequently, it may be desirable to increase intake manifold vacuum via a plurality of control actions including reducing and/or eliminating creep torque while providing vacuum via ejector 20. In this way, ejector 20 may provide even deeper vacuum to the vehicle vacuum system.

Vacuum reservoir 138 provides vacuum to brake booster 140 via check valve 65. Vacuum reservoir 138 may also provide vacuum to other vacuum consumers such as turbocharger waste gate actuators, heating and ventilation actuators, driveline actuators (e.g., four wheel drive actuators), fuel vapor purging systems, engine crankcase ventilation, and fuel system leak testing systems. Check valve 61 limits air flow from vacuum reservoir 138 to secondary vacuum consumers (e.g., vacuum consumers other than the vehicle braking system). Brake booster 140 may include an internal vacuum reservoir, and it may amplify force provided by foot 152 via brake pedal 150 to master cylinder 148 for applying vehicle brakes (not shown).

Distributorless ignition system 88 provides an ignition spark to combustion chamber 30 via spark plug 92 in response to controller 12. Universal Exhaust Gas Oxygen (UEGO) sensor 126 is shown coupled to exhaust manifold 48 upstream of catalytic converter 70. Alternatively, a two-state exhaust gas oxygen sensor may be substituted for UEGO sensor 126.

Converter 70 can include multiple catalyst bricks, in one example. In another example, multiple emission control devices, each with multiple bricks, can be used. Converter 70 can be a three-way type catalyst in one example.

Controller 12 is shown in FIG. 1 as a conventional microcomputer including: microprocessor unit 102, input/output ports 104, read-only memory 106, random access memory 108, keep alive memory 110, and a conventional data bus. Controller 12 is shown receiving various signals from sensors coupled to engine 10, in addition to those signals previously discussed, including: engine coolant temperature (ECT) from temperature sensor 112 coupled to cooling sleeve 114; a position sensor 134 coupled to an accelerator pedal 130 for sensing accelerator position adjusted by foot 132; a position sensor 154 coupled to brake pedal 150 for sensing brake pedal position; a knock sensor for determining ignition of end gases (not shown); a measurement of engine manifold pressure (MAP) from pressure sensor 121 coupled to intake manifold 44; a measurement of boost pressure from pressure sensor 122 coupled to boost chamber 46; an engine position sensor from a Hall effect sensor 118 sensing crankshaft 40 position; a measurement of air mass entering the engine from sensor 120 (e.g., a hot wire air flow meter); and a measurement of throttle position from sensor 58. Barometric pressure may also be sensed via sensor 183 for processing by controller 12. In a preferred aspect of the present description, engine position sensor 118 produces a predetermined number of equally spaced pulses every revolution of the crankshaft from which engine speed (RPM) can be determined.

In some examples, the engine may be coupled to an electric motor/battery system in a hybrid vehicle. The hybrid vehicle may have a parallel configuration, series configuration, or variation or combinations thereof. Further, in some examples, other engine configurations may be employed, for example a diesel engine.

During operation, each cylinder within engine 10 typically undergoes a four stroke cycle: the cycle includes the intake stroke, compression stroke, expansion stroke, and exhaust stroke. During the intake stroke, generally, the exhaust valve 54 closes and intake valve 52 opens. Air is introduced into combustion chamber 30 via intake manifold 44, and piston 36 moves to the bottom of the cylinder so as to increase the volume within combustion chamber 30. The position at which piston 36 is near the bottom of the cylinder and at the end of its stroke (e.g., when combustion chamber 30 is at its largest volume) is typically referred to by those

of skill in the art as bottom dead center (BDC). During the compression stroke, intake valve **52** and exhaust valve **54** are closed. Piston **36** moves toward the cylinder head so as to compress the air within combustion chamber **30**. The point at which piston **36** is at the end of its stroke and closest to the cylinder head (e.g., when combustion chamber **30** is at its smallest volume) is typically referred to by those of skill in the art as top dead center (TDC). In a process hereinafter referred to as injection, fuel is introduced into the combustion chamber. In a process hereinafter referred to as ignition, the injected fuel is ignited by known ignition means such as spark plug **92**, resulting in combustion. During the expansion stroke, the expanding gases push piston **36** back to BDC. Crankshaft **40** converts piston movement into a rotational torque of the rotary shaft. Finally, during the exhaust stroke, the exhaust valve **54** opens to release the combusted air-fuel mixture to exhaust manifold **48** and the piston returns to TDC. Note that the above described is merely an example, and that intake and exhaust valve opening and/or closing timings may vary, such as to provide positive or negative valve overlap, late intake valve closing, or various other examples.

FIG. 2 is a block diagram of a vehicle powertrain **200**. Powertrain **200** may be powered by engine **10**. Engine **10** may be started with an engine starting system. Further, the output torque of engine **10** may be controlled by controller **12** through control of throttle **58**, the fuel injectors, control of the ignition timing of ignition system **88**, and timing of intake valves **52**. Torque is further controlled at the driven wheels not only by controlling the output engine torque, but also by controlling torque transmitted through the transmission via controlling slippage of clutch **206** or selecting the transmission gear.

An engine output torque may be transmitted to torque converter **206** to drive automatic transmission **208** via transmission input shaft **236**. Torque converter **206** includes an impeller rotor fixed to the output shaft of engine **10** and a turbine rotor fixed to the input shaft **236** of transmission **208**. The turbine of torque converter **206** can be driven hydro-dynamically by the impeller of torque converter **206**. Thus, torque converter **206** may provide a "hydraulic coupling" between output shaft of engine **10** and input shaft **236** of transmission **208**. Torque converter **206** further includes a torque converter clutch (e.g., a bypass clutch). The torque converter clutch is controllable across a range between an engaged position (e.g., a lock-up position, an applied position, etc.) and a disengaged position (e.g., an unlocked position, etc.). In the engaged position, the converter clutch mechanically connects the impeller and the turbine of torque converter **206** thereby substantially discounting the hydraulic coupling between these components. In the disengaged position, the converter clutch permits the hydraulic coupling between the impeller and the turbine of torque converter **206**. When the torque converter clutch is disengaged, the hydraulic coupling between the impeller and the turbine of torque converter **206** absorbs and attenuates unacceptable vibrations and other disturbances in the powertrain.

The torque converter clutch may be controlled through the operation of a clutch valve. In response to a control signal, clutch valve pressurizes and vents the converter clutch to engage and disengage. The operation of torque converter **206** can be controlled such that converter clutch is neither fully engaged nor fully disengaged and instead is modulated to produce a magnitude of slip in torque converter **206**. The slip of torque converter **206** corresponds to the difference in the speeds of the impeller and the turbine of torque converter **206**. The slip of torque converter **206** approaches zero as

converter clutch approaches the fully engaged position. Conversely, the magnitude of the slip of torque converter **206** becomes larger as the converter clutch moves toward the disengaged position. When operated to produce a variable magnitude of slip, torque converter **206** can be used to absorb vibrations by increasing the slip, thus causing a greater portion of the engine torque to be passed from the impeller to the turbine of torque converter **206** through hydro-dynamic action.

Torque output from the automatic transmission **208** may be in turn relayed to wheels **216** to propel the vehicle via transmission output shaft **234**. Specifically, automatic transmission **208** may transfer an input driving torque at the input shaft **236** responsive to a vehicle traveling conditions before transmitting an output driving torque to the wheels.

If the automatic transmission stops producing a creep torque, it may be advantageous for the brake system to provide a torque that opposes vehicle reverse motion if the transmission is in a forward gear and opposes vehicle forward motion if the transmission is in a reverse gear. The brake system may increase brake system pressure during such conditions. Effectively, the vehicle brakes may function as a directional ratchet mechanism. It may do this in a number of ways, but one method is to arrange the transmission or wheel brakes to be self-actuating such that the intended motion is opposed with far less torque than is the unintended motion. Further, a frictional force may be applied to wheels **216** by engaging wheel brakes **218**. In one example, wheel brakes **218** may be engaged in response to the driver pressing his foot on a brake pedal (not shown). In the same way, a frictional force may be reduced to wheels **216** by disengaging wheel brakes **218** in response to the driver releasing his foot from a brake pedal. Further, vehicle brakes may apply a frictional force to wheels **216** as part of an automated engine stopping procedure.

Gear clutches **230** may be selectively applied via gear actuator **233**. Gear actuator **233** may be electrically or hydraulically operated. Creep may be reduced in an automatic transmission via slipping a gear clutch **230**. For example, if the vehicle is stopped a gear clutch (e.g., 1st, 2nd, 3rd, or 4th gear clutch) may be slipped to reduce creep torque.

Transmission input speed may be monitored via transmission input shaft speed sensor **240**. Transmission output speed may be monitored via transmission output shaft speed sensor **244**. In some examples, inclinometer **250** may provide vehicle road grade data to controller **12** so that torque converter **206** may be controlled (e.g., increase or decrease clutch apply pressure and adjust clutch engagement timing) via controller **12**. In some examples, torque transmitted through transmission **208** may be determined via a torque sensor **245**.

A controller **12** may be configured to receive inputs from engine **10**, and accordingly control a torque output of the engine and/or operation of the torque converter, transmission, clutches, and/or brakes. As one example, a torque output may be controlled by adjusting a combination of spark timing, fuel pulse width, fuel pulse timing, and/or air charge, by controlling air inlet throttle opening and/or valve timing, valve lift and boost for turbo- or super-charged engines. In the case of a diesel engine, controller **12** may control the engine torque output by controlling a combination of fuel pulse width, fuel pulse timing, and air charge. In all cases, engine control may be performed on a cylinder-by-cylinder basis to control the engine torque output.

In some examples, wheel brakes **218** may be held in an applied state after a driver releases a brake pedal and before a threshold driver demand torque is provided. By holding the

state of wheel brakes **218**, it may be possible to reduce the possibility of the vehicle rolling when the driver releases the brake on a hill.

FIG. **3** shows a high-level flow chart for an example method **300** for preventing wheel slippage on a stopped vehicle in accordance with the current disclosure. In particular, method **300** relates to preventing wheel slippage on a stopped vehicle before it occurs. Method **300** will be described herein with reference to the components and systems depicted in FIGS. **1** and **2**, though it should be understood that the method may be applied to other systems without departing from the scope of this disclosure. Method **300** may be carried out by controller **12**, and may be stored as executable instructions in non-transitory memory.

Method **300** may begin at **305**. At **305**, method **300** may include evaluating operating conditions. Operating conditions may include, but are not limited to, accelerator pedal position, brake pedal position, engine idle speed, brake boost vacuum, engine idle speed, front wheel speed, rear wheel speed, ignition timing, and torque output by the transmission. Method **300** may then proceed to **310**.

At **310**, method **300** may include determining if the accelerator pedal **130** is depressed. If the accelerator pedal **130** is pressed, then creep torque is not an issue and method **300** may proceed to **335**. At **335**, method **300** may include maintaining the operating conditions evaluated at **305**. Method **300** may then end. Returning to **310**, if the accelerator pedal **130** is not pressed, method **300** may then proceed to **315**.

At **315**, method **300** may include evaluating a non-driven wheel speed and comparing this speed to a threshold $v_{threshold}$. A non-driven wheel refers to a wheel of the vehicle that is not receiving torque, for example, a front wheel in a rear-wheel drive vehicle. The non-driven wheel speed threshold $v_{threshold}$ may be set to zero or may be approaching zero. If the non-driven wheel speed is greater than the threshold $v_{threshold}$, then the vehicle is in motion. Method **300** may proceed to **335**. At **335**, method **300** may include maintaining the operating conditions evaluated at **305**. Method **300** may then end. Returning to **315**, if the speed is less than or equal to the threshold $v_{threshold}$, then the vehicle is not in motion. Method **300** may then continue to **320**.

At **320**, method **300** may include measuring a brake boost vacuum and comparing this measurement to a vacuum threshold $V_{threshold}$. If the brake boost vacuum is greater than the threshold $V_{threshold}$, then there is sufficient brake boost vacuum to apply the brakes. Method **300** may proceed to **335**. At **335**, method **300** may include maintaining the operating conditions evaluated at **305**. Method **300** may then end. Returning to **320**, if the brake boost vacuum is less than or equal to the threshold $V_{threshold}$, then there is not sufficient brake boost vacuum to apply the brakes. A low brake boost vacuum may occur if the engine idle speed is high and the engine is in gear, or if the vehicle is at a high altitude. Method **300** may then continue to **325**.

At **325**, method **300** may include measuring an engine idle speed and comparing this measurement to a threshold $Sp_{threshold}$. Threshold $Sp_{threshold}$ may be predetermined such that below the threshold, the creep torque is too low to cause wheel slippage. Therefore, if the engine idle speed is less than the threshold $Sp_{threshold}$, method **300** may proceed to **335**. At **335**, method **300** may include maintaining the operating conditions evaluated at **305**. Method **300** may then end. Otherwise, if the engine idle speed is greater than the threshold $Sp_{threshold}$, then the creep torque is high and wheel slippage may be possible. Method **300** may then continue to **330**.

At **330**, method **300** may include reducing torque to the driven wheels. In the preferred embodiment **326**, reducing torque to the driven wheels may include upshifting the transmission. Upshifting the transmission, say from first gear to second or third gear depending on the engine idle speed, reduces the creep torque to the driven wheels, thereby reducing the likelihood of wheel slippage. The transmission may be upshifted from first gear to second gear or third gear responsive to the engine idle speed. A higher engine idle speed may correspond to a higher transmission gear. For example, if the engine idle speed is between 750 to 1000 rotations per minute (rpm), the transmission may upshift from first to second gear. If the engine idle speed is between 1000 and 1200 rpm, the transmission may upshift from first to third gear. In this way, a consistent creep torque may be provided for any engine idle speed.

In another embodiment **327**, reducing torque to the driven wheels may include slipping the transmission clutch **230**. Slipping the transmission clutch comprises rapidly disengaging and engaging the clutch **230** so that the transmission **208** is not fully in gear, thereby reducing the torque delivered to the wheels. Though slipping the clutch is typically undesirable, the use of this technique would be brief and infrequent so that negative effects due to friction are negligible. Slipping the transmission clutch may otherwise comprise slipping the torque converter clutch as described herein and with regard to FIG. **2**.

In another embodiment **328**, reducing torque to the driven wheels may include retarding ignition timing. Retarding ignition timing comprises igniting injected fuel in the combustion chamber **30** after the piston is in TDC or after a normal ignition advance with respect to TDC, resulting in less efficient combustion and therefore less torque.

The particular method in **330** of reducing torque to driven wheels implemented to prevent wheel slippage may be chosen responsive to operating conditions. Further, the operation and the amounts may be determined from barometric pressure, road grade, manifold vacuum, engine speed, clutch pressure, road friction, etc. Method **300** may then end.

The method of reducing torque to driven wheels may not be limited to the operations **330**. Other techniques known to a person skilled in the arts may be used to reduce torque produced by the engine, for example, throttling air inducted into the engine, adjusting timing of a device for injecting fuel into the engine, adjusting ignition timing, adjusting valve timing, or adjusting air forced into the engine by a compressor in the case of a turbocharged or supercharged engine.

FIG. **4** shows a high-level flow chart for an example method **400** for preventing wheel slippage of a stopped vehicle in accordance with the current disclosure. In particular, method **400** relates to reducing wheel slippage of a stopped vehicle while wheel slippage is occurring. Method **400** will be described herein with reference to the components and systems of FIGS. **1** and **2**, though it should be understood that the method may be applied to other systems without departing from the scope of this disclosure. Method **400** may be carried out by controller **12**, and may be stored as executable instructions in non-transitory memory.

Method **400** may begin at **405**. At **405**, method **400** may include evaluating operating conditions. Operating conditions may include, but are not limited to, accelerator pedal position, brake pedal position, engine idle speed, brake boost vacuum, engine idle speed, front wheel speed, rear wheel speed, ignition timing, torque output by the transmission, and the magnitude of driven wheel slip. Method **400** may then proceed to **410**.

At **410**, method **400** may include determining if the accelerator pedal **130** is depressed. If the accelerator pedal **130** is pressed, then the vehicle is in motion and creep torque is not an issue. Method **400** may proceed to **425**. At **425**, method **400** may include maintaining the operating conditions evaluated at **405**. Method **400** may then end. Returning to **410**, if the accelerator pedal **130** is not pressed, there may be creep torque and so method **400** may continue to **415**.

At **415**, method **400** may include determining if the non-driven wheel speed is zero. If the non-driven wheel speed is not zero, then the vehicle is in motion and method **400** may proceed to **425**. At **425**, method **400** may include maintaining the operating conditions evaluated at **405**. Method **400** may then end. Returning to **415**, if the non-driven wheel speed is zero, then it is possible that wheel slippage may occur. Method **400** may then continue to **420**.

At **420**, method **400** may include measuring the driven wheel slippage and comparing this measurement to a slip threshold. This threshold may be zero or approaching zero. If the driven wheel slippage is below the slip threshold, then there is no wheel slippage and method **400** may proceed to **425**. At **425**, method **400** may include maintaining the operating conditions evaluated at **405**. Method **400** may then end. Returning to **420**, if the driven wheel slippage is above the slip threshold, then there is wheel slippage due to creep torque. Method **400** may then continue to **430**.

At **430**, method **400** may include reducing torque to driven wheels, applying additional brake force to driven wheels, or some combination of reducing torque to driven wheels and applying additional brake force to driven wheels. In the preferred embodiment **431**, reducing torque to driven wheels includes upshifting the transmission. Upshifting the transmission, say from first gear to second or third gear depending on the engine idle speed, reduces the creep torque to the driven wheels, thereby reducing the likelihood of wheel slippage. The transmission may be upshifted from first gear to second gear or third gear responsive to the engine idle speed. A higher engine idle speed may correspond to a higher transmission gear. For example, if the engine idle speed is between 750 to 1000 rotations per minute (rpm), the transmission may upshift from first to second gear. If the engine idle speed is between 1000 and 1200 rpm, the transmission may upshift from first to third gear. In this way, a consistent creep torque may be provided for any engine idle speed.

In another embodiment **432**, reducing torque to the driven wheels may include slipping the transmission clutch. Slipping the transmission clutch comprises rapidly disengaging and engaging the clutch so that the transmission is not fully in gear, thereby reducing the torque delivered to the wheels. Though slipping the clutch is typically undesirable, the use of this technique would be brief and infrequent so that negative effects due to friction are negligible. Slipping the transmission clutch may otherwise comprise slipping the torque converter clutch as described herein and with regard to FIG. **2**.

In another embodiment **433**, reducing torque to the driven wheels may include shifting the transmission to neutral. Shifting the transmission to neutral eliminates the transmission of torque through the powertrain to the rear wheels, thereby eliminating any creep torque.

In another embodiment **434**, reducing torque to the driven wheels may include retarding ignition timing. Retarding ignition timing comprises igniting injected fuel in the combustion chamber **30** after the piston is in TDC or after a normal ignition advance with respect to TDC, resulting in less efficient combustion and therefore less torque.

Returning to **430**, method **400** may also include applying additional brake force to the driven wheels. In one embodiment **435**, applying additional brake force to the driven wheels may include increasing brake pressure to the driven wheels. Applying additional brake force to driven wheels may only be possible when the brake booster vacuum is above a vacuum threshold.

In another embodiment **436**, applying additional brake force to the driven wheels may include applying an electric parking brake to the driven wheels. Applying an electric parking brake to the driven wheels disables the driven wheels ability to spin.

The particular operation or operations in **430** of reducing torque to driven wheels or applying additional brake force to driven wheels implemented to prevent wheel slippage may be chosen responsive to operating conditions. Further, the operation and the amounts may be determined from barometric pressure, road grade, manifold vacuum, engine speed, clutch pressure, road friction, etc.

The method of reducing torque to driven wheels may not be limited to the operations **430**. Other techniques known to a person skilled in the arts may be used to reduce torque produced by the engine, for example, throttling air inducted into the engine, adjusting timing of a device for injecting fuel into the engine, adjusting ignition timing, adjusting valve timing, or adjusting air forced into the engine by a compressor in the case of a turbocharged or supercharged engine.

Method **400** may then continue to **420** in order to determine if wheel slippage still occurs. If the driven wheel slippage is still above a threshold, method **400** returns to **430**. At **430**, one or more of the operations is applied as disclosed herein. Method **400** may loop between **420** and **430**, applying one or more operations until the driven wheel slippage is below the slip threshold. Method **400** may then proceed to **425**. At **425**, method **400** may include maintaining the operating conditions. The operating conditions may include the conditions evaluated at **405**, and may also include the new operating conditions established at **430**. Method **400** may then end.

FIG. **5** shows a high-level flow chart for an example method **500** for preventing wheel slippage of a stopped vehicle in accordance with the current disclosure. In particular, method **500** relates to giving consistent creep torque over the range of engine idle speeds. Method **500** will be described herein with reference to the components and systems depicted in FIGS. **1** and **2**, though it should be understood that the method may be applied to other systems without departing from the scope of this disclosure. Method **500** may be carried out by controller **12**, and may be stored as executable instructions in non-transitory memory.

Method **500** may begin at **505**. At **505**, method **500** may include evaluating operating conditions. Operating conditions may include, but are not limited to, accelerator pedal position, brake pedal position, engine idle speed, brake boost vacuum, engine idle speed, front wheel speed, rear wheel speed, ignition timing, and torque output by the transmission. Method **500** may then proceed to **510**.

At **510**, method **500** may include determining if the accelerator pedal **130** is depressed. If the accelerator pedal **130** is pressed, then the vehicle is in motion and creep torque is not a concern. Method **500** may proceed to **530**. At **530**, method **500** may include maintaining the operating conditions evaluated at **505**. Method **500** may then end. Returning to **510**, if the accelerator pedal **130** is not pressed, then it is possible that creep torque is a concern. Method **500** may then continue to **515**.

At **515**, method **500** may include measuring the non-driven wheel speed and comparing this measurement to a threshold $v_{threshold}$. If the non-driven wheel speed is greater than the threshold $v_{threshold}$, then the vehicle is in motion and method **500** may proceed to **530**. At **530**, method **500** may include maintaining the operating conditions evaluated at **505**. Method **500** may then end. Returning to **515**, if the non-driven wheel speed is less than or equal to the threshold $v_{threshold}$, then the vehicle is not in motion and creep torque may be a concern. Method **500** may then continue to **520**.

At **520**, method **500** may include measuring the engine idle speed and comparing this measurement to a threshold $Sp_{threshold}$. If the engine idle speed is less than the threshold $Sp_{threshold}$, then creep torque may not be a concern and method **500** may proceed to **530**. At **530**, method **500** may include maintaining the operating conditions evaluated at **505**. Method **500** may then end. Returning to **520**, if the engine idle speed is greater than or equal to the threshold $Sp_{threshold}$, then method **500** may continue to **525**.

Continuing at **525**, method **500** may include applying substantially constant torque to driven wheels by applying transmission gear related to engine idle speed. For example, if the engine idle speed is in the range 550 to 750 rotations per minute (rpm), the transmission gear will be in first gear. If the engine idle speed is in the range 750 to 1000 rpm, the transmission gear will be shifted to second gear. If the engine idle speed is in the range 1000 to 1200 rpm, the transmission gear will be shifted to third gear. In this way, the transmission provides a consistent creep torque rather than a variable torque responsive to engine idle speed. Method **500** may then end.

FIG. **6** shows an example timeline **600** for preventing wheel slippage on a stopped vehicle using the method described herein and with regards to FIG. **3**. Timeline **600** includes vertical dashed lines t_0, t_1, t_2, t_3, and t_4 to represent times of interest during the sequence. The x-axis for all plots represents time, and time increases from the left side of FIG. **6** to the right side of FIG. **6**. Timeline **600** is for illustrative purposes and therefore is not drawn to scale.

Timeline **600** includes plot **610**, indicating the brake pedal position over time. Above the brake pedal position threshold **615**, the brakes are applied to the non-driven wheels. Timeline **600** also includes plot **620**, indicating the vehicle speed as measured by the non-driven wheels over time; plot **630**, indicating the engine idle speed over time; plot **640**, indicating the transmission gear over time; plot **650**, indicating the creep torque over time; and plot **660**, indicating the brake boost vacuum over time. Line **625** represents the vehicle speed threshold $v_{threshold}$. Line **635** represents the engine idle speed threshold $Sp_{threshold}$. Line **665** represents the brake boost vacuum threshold $V_{threshold}$.

At time t_0, the driver has applied the brakes to the non-driven wheels as shown by plot **610**. The vehicle speed as measured by the non-driven wheels is therefore zero, as shown by plot **620**. The engine idle speed is well above the threshold, as shown by plot **630**. Since the transmission is in first gear, as shown by plot **640**, a creep torque is present. Plot **650** shows that the creep torque is very high, which is a result of the high engine idle speed. Furthermore, the high engine idle speed yields a low brake boost vacuum, as shown by plot **660**.

From time t_1 to t_2, the transmission upshifts from first gear to second gear while the brakes are still applied and the vehicle is still not in motion. As a result, the creep torque is reduced to a level consistent with a normal engine idle speed. At time t_2, the engine idle speed is still above threshold **635** and the brake boost vacuum is still below

threshold **665**. Meanwhile, the brakes are maintained on the non-driven wheels and so the vehicle speed as measured by the non-driven wheels is still zero. However, the creep torque is at a manageable level and the possibility of unintended lateral movement of the driven wheels is minimized.

FIG. **7** shows an example timeline **700** for stopping wheel slippage on a stopped vehicle using the method described herein and with regard to FIG. **4**. Timeline **700** includes vertical dashed lines t_0, t_1, t_2, t_3, and t_4 to represent times of interest during the sequence. The x-axis for all plots represents time, and time increases from the left side of FIG. **7** to the right side of FIG. **7**. Timeline **700** is for illustrative purposes and therefore is not drawn to scale.

Timeline **700** includes plot **710**, indicating the brake pedal position over time. Above the brake pedal position threshold **715**, the brakes are applied to the non-driven wheels. Timeline **700** also includes plot **720**, indicating the vehicle speed as measured by the non-driven wheels over time; plot **730**, indicating the driven wheel slippage over time; plot **740**, indicating the engine idle speed over time; plot **750**, indicating the transmission gear over time; plot **760**, indicating the creep torque over time; and plot **770**, indicating the brake boost vacuum over time. Line **725** represents the vehicle speed threshold $v_{threshold}=0$. Line **735** represents a driven wheel slip threshold. Line **745** represents an engine idle speed threshold. Line **775** represents a brake boost vacuum threshold. Time **700** also includes plot **780**, indicating the clutch slippage over time. Line **785** represents a clutch slip threshold.

At time t_0, the driver has applied the brakes to the non-driven wheels and thus the vehicle is not moving as measured by the non-driven wheels, as shown in plots **710** and **720**. However, as respectively shown in plots **740**, **750**, and **760**, the engine idle speed is high and the transmission is in first gear, resulting in a high creep torque. Plot **770** shows that insufficient brake boost vacuum is available to the brakes, so there is a substantial amount of driven wheel slippage as depicted in plot **730**. Since the driven wheel slippage is above the slip threshold, the entry conditions for the method of FIG. **4** are met at t_0.

From times t_1 to t_2, the transmission upshifts from first gear to second gear while the brakes are still applied and the vehicle is not in motion. The transmission upshift reduces the creep torque to the driven wheels, thereby reducing the driven wheel slippage. However, at t_3 the wheel slippage is still above the slip threshold **735** and must be further reduced. Since there is still insufficient brake boost vacuum available, it is possible to reduce the engine idle speed below the idle speed threshold so that brake boost vacuum may be increased. However, it may be preferable to apply another method for reducing the creep torque, such as slipping the clutch.

Prior to time t_3, the clutch begins to slip as shown by plot **780**. From times t_3 to t_4, the clutch slippage is above a clutch slippage threshold **785** and so torque is not being transmitted to the driven wheels. At time t_4, the creep torque is reduced below a threshold **765** and the wheels are no longer slipping. The driven wheel slippage has been effectively reduced or eliminated.

In another representation, a method comprises applying a brake force concurrently to all four wheels of a motor vehicle to slow down said vehicle toward a non-moving condition while torque continues to be applied to each of its driven wheels, and reducing wheel slippage of said driven wheels by reducing said applied torque only after vehicle speed has fallen below a low speed threshold, which may

include a non-forward-moving condition. The reducing torque of the driven wheels may include upshifting an automatic transmission coupled between an engine of said vehicle and said driven wheels. Furthermore, such operation may occur while and be responsive to engine speed is higher than a high engine idle speed threshold. Further, such operation may occur while and be responsive to a situation where the transmission's torque converter create a torque larger than a threshold nominal creep torque, thereby driving the rear wheels. Furthermore, such operation can occur during and be responsive to a condition where the engine vacuum is lower than a threshold where the engine is throttled less at the high engine speed as compared to a lower engine idle speed, and vacuum is consumed by the front end accessory drive, torque converter, catalyst heating, and cold engine friction needs. Thus such operation can be during and responsive to stored brake booster vacuum lower than a threshold, and further adjusted responsive to atmospheric pressure at high altitude lower than a threshold, triggering the and adjusting an amount of the torque applied to each of the four wheels of the vehicle. For example, increase torque may be applied at higher engine speed, lower atmospheric pressure, lower stored vacuum (e.g., higher vacuum pressure), engine throttling less than a threshold and/or combinations thereof.

Note that the example control and estimation routines included herein can be used with various engine and/or vehicle system configurations. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the engine control system.

It will be appreciated that the configurations and routines disclosed herein are exemplary in nature, and that these specific embodiments are not to be considered in a limiting sense, because numerous variations are possible. For example, the above technology can be applied to V-6, I-4, I-6, V-12, opposed 4, and other engine types. The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various systems and configurations, and other features, functions, and/or properties disclosed herein.

The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

The invention claimed is:

1. A method, comprising:
applying a brake force to all four wheels of a motor vehicle to stop said vehicle while torque continues to be applied to its driven wheels; and
preventing wheel slippage of said driven wheels by reducing said applied torque when said vehicle is stopped or nearly stopped from moving in a forward direction, wherein said reducing said applied torque is both initiated before said wheel slippage occurs and after said wheel slippage occurs.

2. The method recited in claim 1, wherein said reducing said applied torque comprises upshifting an automatic transmission coupled between an engine of said vehicle and said driven wheels.

3. The method recited in claim 2, wherein said reducing said applied torque comprises slipping a clutch of said transmission.

4. The method recited in claim 1, wherein said reducing said applied torque comprises reducing a speed of an engine of said vehicle.

5. The method recited in claim 4, wherein said engine speed is reduced by one or more of the following: throttling air inducted into said engine, retarding timing of an ignition device coupled to combustion chambers of the engine, or adjusting timing of a device for injecting fuel into said engine.

6. A method, comprising:
applying a brake force to all four wheels of a motor vehicle to stop said vehicle while torque continues to be applied to its driven wheels; and
in response to wheel slippage of said driven wheels when said vehicle is stopped from moving in a forward direction, reducing said applied torque to reduce said slippage, wherein said reducing said applied torque comprises upshifting an automatic transmission coupled between an engine of said vehicle and said driven wheels, said applying of the brake force responsive to a brake booster vacuum level and creep torque.

7. The method recited in claim 6, wherein said reducing said applied torque comprises slipping a clutch of said transmission.

8. The method recited in claim 6, wherein said reducing said applied torque comprises reducing a speed of the engine of said vehicle.

9. The method recited in claim 8, wherein said engine speed is reduced by one or more of the following: throttling air inducted into said engine, retarding timing of an ignition device coupled to combustion chambers of the engine, or adjusting timing of a device for injecting fuel into said engine.

10. The method recited in claim 6, further comprising increasing brake pressure to a braking device applied to said driven wheels in response to said wheel slippage.

11. The method recited in claim 6, further comprising applying an electric parking brake to said driven wheels in response to said wheel slippage.

12. The method recited in claim 6, further comprising a transmission gear schedule having a plurality of gears related to a range of speeds of said engine to provide a substantially constant torque applied to said driven wheels over said range of speeds of said engine.

13. A method, comprising:

applying a brake force to all four wheels of a motor vehicle to stop said vehicle while torque continues to be applied to its driven wheels; and

preventing wheel slippage of said driven wheels by reducing said applied torque when said vehicle is stopped or nearly stopped from moving in a forward direction, wherein said reducing said applied torque comprises reducing a speed of an engine of said vehicle and wherein said engine speed is reduced by one or more of the following: throttling air inducted into said engine, retarding timing of an ignition device coupled to combustion chambers of the engine, or adjusting timing of a device for injecting fuel into said engine.

14. The method of claim 13, wherein said reducing said applied torque is initiated before said wheel slippage occurs.

15. The method of claim 14, further comprising wherein said reducing said applied torque occurs when said vehicle has a brake boost vacuum that is less than a threshold vacuum.

16. The method of claim 13, wherein said preventing wheel slippage by reducing said applied torque is initiated in response to occurrence of said wheel slippage.

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